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Radiative transfer in the Dynamic Atmospheres of Mira-type Variables.

Jeffrey L. Linsky & Donald G. Luttermoser, P.I. (University of Colorado)

This NASA grant covers our ADP research program, which involved detailed radiative transfer calculations of hydrodynamic models of pulsating asymptotic giant branch stars. Synthetic spectra resulting from these calculations are compared with IUE observations of these stars to test the validity of the models.

## 1 Summary of this Research:

We initially announced this research project to the scientific community at the Boston meeting of the American Astronomical Society in January 1989 (Luttermoser *et al.* 1989). We have carried out radiative transfer calculations for a 3000 K,  $1 M_{\odot}$ ,  $240 R_{\odot}$ , 320 day pulsation period model for a preliminary test case of a prototype Mira-type variable star and a 3600 K,  $0.8 M_{\odot}$ ,  $145 R_{\odot}$ , 149 day pulsation period model representative of the Mira-type variable S Car. IUE spectra of the Mg II *h* and *k* lines for S Car are compared to the synthetic spectra. The radiative transfer calculations for the cooler model demonstrate that the approximations used by Bowen (1988, ApJ, 329, 299) for radiative cooling underestimates total hydrogen cooling in the main, innermost shock (Luttermoser and Bowen 1990). Since Lyman  $\alpha$  is the only transition included in his original cooling rate calculations for hydrogen, ignoring other important hydrogen coolants leads to shocks that are too hot for these stars. Lyman  $\alpha$  and the Balmer continuum photons from the innermost shock have a profound effect on heating the outer regions of the atmosphere (Luttermoser and Johnson 1991). We have found other interesting effects in the hydrogen calculations (Luttermoser and Bowen 1991a) which are described in the attached abstract of a paper to be presented at the 7th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun in Tucson this October. A full discussion of the hydrogen calculations will be presented in Luttermoser and Bowen (1991b).

The preliminary report of the Mg II calculations was presented by Luttermoser *et al.* (1990). The Mg II calculations reproduce the temporal variations of the Mg II *h* and *k* lines in the spectrum of S Car however the profile shapes are not reproduced by the models. Substantial amounts of absorption by overlying material is responsible for the discrepancies between the synthetic and observed spectra. A full discussion of the magnesium calculations will be presented in Luttermoser and Bowen (1991c).

## 2 Comments on the Success of this Research Project:

The information gained by this project is of fundamental importance in the understanding of the atmospheric structure of pulsating variables. This information however came at a tremendous cost of computer time. We find that the equivalent two-level approach for a NLTE solution of the coupled radiative transfer and statistical equilibrium equations is not well suited for this type of research (*i.e.*, radiative transfer in dynamic atmospheres). It however has given us useful insight to future projects involving hydrodynamic radiative transfer for the Mira-type variables. Details of the computational difficulties encountered in this research is described in Luttermoser and Johnson (1991) and Luttermoser and Bowen (1991b).

### Papers and Abstracts Concerning this Research:

- Luttermoser, D.G. and Bowen, G.H. 1990, *Radiative Transfer in the Dynamic Atmospheres of Long Period Variables*, in Sixth Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, ed. G. Wallerstein (Astronomical Society of the Pacific: San Francisco), 491.
- Luttermoser, D.G. and Bowen, G.H. 1991a, *NLTE Synthetic Spectra of the Mira-type Variable S Car*, in Seventh Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, ed. M. Giampapa (Astronomical Society of the Pacific: San Francisco), (in press).
- Luttermoser, D.G. and Bowen, G.H. 1991b, *NLTE Synthetic Spectra of the Mira-type Variable S Car: I. Hydrogen*, ApJ, (in preparation).
- Luttermoser, D.G. and Bowen, G.H. 1991c, *NLTE Synthetic Spectra of the Mira-type Variable S Car: II. Magnesium*, ApJ, (in preparation).
- Luttermoser, D.G., Bowen, G.H., Willson, L.A., Avrett, E.H., and Johnson, H.R. 1989, *A New Collaboration in Modelling the Atmospheres of Mira-type Variables*, Bulletin of the American Astronomical Society, **20**, 996.
- Luttermoser, D.G., Bowen, G.H., Willson, L.A., and Brugel, E.W. 1990, *Synthetic Mg II h and k Line Profiles of Mira-type Variables*, Bulletin of the American Astronomical Society, **21**, 1117.
- Luttermoser, D.G. and Johnson, H.R. 1991, *Ionization and Excitation in Cool Giant Stars: I. Hydrogen and Helium*, ApJ, (submitted).